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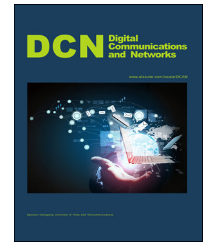

Cognitive assisted living ambient system: a survey

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Abstract
The demographic change towards an aging population is creating a significant impact and introducing drastic challenges to our society. We therefore need to find ways to assist older people to stay independently and prevent social isolation of these population. Information and Communication Technologies (ICT) provide various solutions to help older adults to improve their quality of life, stay healthier, and live independently for a time. Ambient Assisted Living (AAL) is a field to investigate innovative technologies to provide assistance as well as healthcare and rehabilitation to impaired seniors. The paper provides a review of research background and technologies of AAL.

1. Introduction

Population aging has become a global phenomenon as a result of life longevity and declining birth rate of modern society, especially in developed regions. The trend will be more severe and cause larger impact on our society in the coming years [1]. The number of people aged 65 or older is projected to grow from an estimated 524 million in 2010 to nearly 1.5 billion in 2050, with most of the increase in developing countries [2]. Europe currently holds the highest proportion of aging population. As the demographic statistics reports [3], the population over 60 years old is 24.5% of the total of Europe. The growing number of older population will be accompanied with rapid increase in number of people with mental and physical impairments as well as various age-related chronic disease such as hyperactivity disorder, autism spectrum disorders and motor handicap as well as various age-related chronic diseases like cognitive decline[4].

According to [5], up to 19 million population give primary assistance with daily activities to their older or dependent relatives. 70% of individuals cannot live independently and

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need activity assistance and healthcare from caregiver. In 2012, 15.4 million caregivers provided an estimated 17.5 billion hours of unpaid care, valued at more than $216 billion [6]. Costs of caring for people with Alzheimers and other dementia as will cost from estimated $203 billion from 2013 to a projected $1.2 trillion per year by 2050 in the USA. In total, dementia is estimated to cost the UK £23 billion a year. It also indicates that the global cost of dementia in 2010 at $604 billion which is 1% of global GDP and it is likely that these costs will rise sharply in proportion to the number of older people in the coming years [2]. Therefore, this phenomenon of continuously increasing of older population will bring a huge burden and stress to the families and society.

As a consequence of the increasingly aging population, it is necessary to find solutions to improve the living condition and develop more robust, usable, safe but low cost healthcare systems to reduce the burden to society. ICT could play a remarkable role to conquer this challenge. During recent decades, the research on ICT-enabled support for independent living of older adults has been drawing great attention from the communities and governments. There are many potential areas where ICT can be significant to counteract the effects of population aging. The term of Ambient Assisted Living becomes a field to investigate innovative technologies to provide assistance as well as health-care and rehabilitation to senior people with impairment, especially for people with some cognitive impairment living on their own. These innovative applications enable them to live independently, comfortably, stately and stay healthily throughout their lifespan, namely ageing well-being.

In the past years, AAL research has been adopted worldwide and became a very active research area. Europe Action Plan for Aging Well and Europe AAL Joint Program has been launched by the EU for cultivating the development of innovative ICT-based products, services and systems for the process of aging well at home, in the community and at work, therefore improving the quality of life, the participation in social life, skills and the employability of older people and reducing the costs of health and social care. A wide variety of research projects has just delivered results or is working on AAL. The outcome of these projects aim is to achieve the overarching goal of the European Innovation Partnership on Active and Healthy aging (EIP AHA), which by 2020 aims to increase the average healthy lifespan of Europeans by 2 years. The Ubiquitous Korea Project are long term projects supported by the government to improve citizen's life especially for the aging and disabled people [7].

The AALIANCE project presents a road-map for Ambient Assisted Living which has significant guidance and provides various strategies for future research and development of this area [8]. A collection of international conferences and journals have focused on ambient assisted living and aging well, such as International Conference on aging, Disability and Independence (ICADI), International Conference on Intelligent Environments (ICIE), AAAI Fall Symposium on Caring Machines: AI in Elder-care, International Workshop on Ambient Assisted Living (IWAAL), and the journal of Ambient Intelligence and Smart Environments (JAIS). The Handbook of Ambient Intelligence and Smart Environment [7] and the Handbook of Ambient Assisted Living [9] aggregate the scientific and engineering contributions related to ambient assisted living worldwide. Furthermore, there have been more publications investigating the studies on AAL and relevant technologies [10].

This survey paper aims to provide an one-stop view and summary of the background of AAL research, especially the technologies and approaches for cognitive assisted for aging population in home environment. We will also explore successful case studies and deployed systems. Finally, we will identify the important current and future challenges.

2. Scenarios and applications of AAL

AAL applications are targeted to accommodate the older or the disabled to live independently and comfortably as long as possible in their living environment. Living environments are not only home, but also various environments such as neighbourhood, shopping mall and other public places. AAL applications consist of complex networks of heterogeneous information appliances and smart artefacts which can assist people with special need in several ways. In [8,11,12] various scenarios and prototypes of AAL services for older people are proposed. We summarise the scenarios of AAL services into the following areas, daily task facilitation, mobility assistance, health-care and rehabilitation, and social inclusion and communication (Fig. 1).

In recent years the progress in ubiquitous computing, wireless technologies, sensor networks, computing processing speeds, mobile services and robotics has essentially sustained the development of AAL applications and makes some envision reality in this area. The advancement of artificial intelligence and the relevant approaches such as context-awareness, agent-based technology, computer vision, machine learning and so on have been investigated to provide more intelligent, flexible and natural services to the users. Since the last decade, there are a number of research projects targeted to address technologies to support daily life of older adults. Some of them have been available for customers.

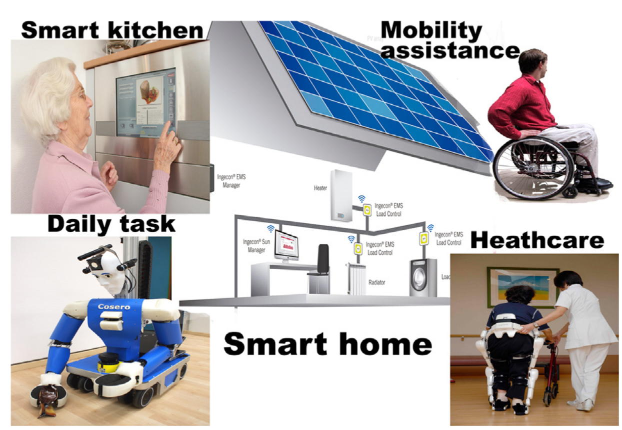


Fig. 1 Typical ambient assisted living environment scenarios: smart home with sensors, appliances, network and computing components, daily task assistance, heathcare, mobility assistance.

2.1. Daily task facilitation in smart home

A smart home is a concept to describe living environment with digital surroundings such as sensors, smart appliances, networks and provides natural feel interactions with humans. A smart home automation is capable of delivering convenient and adaptive services to the dwellers, for instance, automatic actuator for lighting, air condition, temperature control, and food/drinking preparation. It is therefore often used to support people with cognitive impairment who are living independently. In a smart home, daily life activity (DLA) monitoring is an essential component for assisted living. Various digital devices, sensors, cameras, are deployed into the smart environment to continuously monitor and record the activities of dwellers. Activities of daily life are recorded as a symbolic representation. A smart home system can deliver adaptive services with regard to knowledge base of users' lifestyle. Such systems record users' daily activities i.e. when to get up, when to go to sleep, if they like listening radio or news after sleep, and so on. By analysing and processing the recorded activities, the system can recognise the users' habits and produce corresponding services to them.

Service robots are envisaged to assist people with their daily tasks or as part of assistance to the handicapped and the elderly. Domestic robots or service robots are employed to provide assistance for various daily situations, such as fetching and carrying objects from floor, performing cleaning tasks, and emergency support.

There have been a number of smart home projects aimed at assisted living in the world. In Asia, TRON project [13] is an open project on intelligent living environment and assistive technology. In Fig. 2 is TRON Intelligent House established in Tokyo, Japan. The PAPI project and U-house project were founded in Taiwan as part of the TRON project [14]. The Ubiquitous Home [15] proposed and implemented context-aware services in a real-life smart environment. The Robotics Room and The Sensing Room by the University of Tokyo [16] is another prototype of smart home system.

Within the TECNALIA's Health Technologies Unit [17], there are many projects related to AAL. TECNALIA is the largest private Research, Development and Innovation (RDI) group in Spain and one of the leading ones in Europe after a merging process of eight technology centres located in Basque Country (Spain). It involves older people, people with cognitive or physical disabilities, their relatives and caregivers, clinical experts and medical professionals as potential users in the project development.

The EasyLiving project [18] at Microsoft Research developed an architecture and technologies for intelligent environments. The EasyLiving system has evolved smart user interface, dynamic device configuration, remote control, activities tracking which provides flexible support user interaction across a wide variety of tasks and modalities.

House_n [19,20] is a multi-disciplinary project lead by researchers at the MIT Department of Architecture. This project aimed at exploring how new technologies, materials and strategies for design can make dynamic, evolving places that respond to the complexities of life. It has focused on developing new design tools, customisation and fabrication strategies, sensing, and applications related to energy, health, and communication. The project has resulted with some open source tools[2] like Portable Place-Based Research Tools, OPEN Prototype House Initiative, and Portable kit within the Open Source Building Alliance.

Fig. 2 Smart home prototype of TRON project.

The CASAS Smart Home[3] project is a multi-disciplinary research project at Washington State University. It focuses on the creation of an intelligent home environment. In this project, the smart home environment uses intelligent agents, where the status of the residents and their physical surroundings are perceived using sensors and the environment is acted upon using controllers in a way that improves the comfort, safety, and/or productivity of the residents. The developed smart home is an intelligent agent that perceives its environment through sensors, and can act upon the environment through the use of actuators. The system is simple and lightweight so that the capabilities of the smart home can be deployed, evaluated, and scaled accordingly [21,22].

The Ambient Intelligence Research (AIR) Lab at Stanford University focuses on research to develop techniques and applications of ambient intelligence in smart homes and offices and occupancy-aware smart buildings. A space in the AIR lab is set up in the form of a smart room providing natural settings of a living environment while offering an ambient interface to its user through pervasive sensing, processing, and communication. A network of sensing devices is used to monitor work habits and social interactions of the workers, and adaptive personal recommendations are provided to them to promote ergonomic health and social engagement in the smart home setting [23].

The Quality of Life Technology (QoLT) Centre[4] is founded by the US National Science Foundation (NSF) Engineering Research Center (ERC) in Pittsburgh. The Center is jointly run by Carnegie Mellon University and the University of Pittsburgh. It focuses on the development of intelligent systems and assistive technologies that enable older adults and people with disabilities to live more independently. From 2006 to present, they have carried out several projects which address the needs and activities of everyday living by prototyping personal assistive robots, cognitive and behavioral coaches, human awareness and driver assistance

[2] http://architecture.mit.edu/house_n/.
[3] http://ailab.eecs.wsu.edu/casas/.
[4] http://www.cmu.edu/qolt/.

technologies, and human-system interaction with a focus on the social and clinical factors for deployment and adoption.

The Aware Home Research Initiative (AHRI) [24] at Georgia Institute of Technology is a notable project in the area of smart home (Fig. 3). The Aware Home is a 3-story, 5040 square foot facility designed to facilitate research, while providing an authentic home environment. The technical components involved in the home include context awareness and ubiquitous sensing, individual interaction with the home and a smart floor. The project addresses specific applications to older people in three aspects: First, social connections between older parents and their adult children promoting peace of mind for family members. Second, support “everyday cognition” by augmenting those aspects of memory that decline with age and planning capabilities of older residents. Third, handling crisis situations so that appropriate outside services are notified.

MavHome [25] is a project in Washington State University and University of Texas at Arlington in the USA (Fig. 4). They proposed that a system of smart home that can record and learn from the user's behavior and predicate corresponding responses. The scenario of smart home is defined as the following:

> At 6:45am, MavHome turns up the heat because it has learned that the home needs 15 minutes to warm to optimal waking temperature. At 7:00am, the alarm sounds, then the bedroom light and kitchen coffee maker turn on. The user steps into the bathroom and turns on the light. MavHome records this interaction, displays the morning news on the bathroom video screen, and turns on the shower. When the user finishes grooming, the bathroom light turns off while the kitchen light and display turn on, and the news programme moves to the kitchen screen. During breakfast, the user requests the janitor robot to clean the house. When the user leaves for work, MavHome secures the home, and starts the lawn sprinklers despite knowing the 30% predicted chance of rain. Because the refrigerator is low on milk and cheese, MavHome places a grocery order. When the user arrives home, their grocery order has arrived and the hot tub is waiting for them.

Under the 6th and 7th European Framework Programme during last decades, there have been a series of assisted living projects carried out. Some notable projects include ALADIN [26], iSpace [27], RoboCare [28], SYSIASS [29], PERSONA Project [7], and LsW [30]. Within Europe Ambient Assisted Living Joint Programme, there have been about one hundred projects in the 5 consultation calls so far. The list of the projects evolved in the joint programme can be found in.[5]

ALADIN (Ambient Lighting Assistance for an Ageing Population) project proposed a magic lighting system for older adults. The aim of this project is to develop an adaptive lighting system with intelligent open-loop control, which can adapt in response to the users need in various situations but also provides smart eco-energy management. The dynamic lighting system can benefit the users' eye health, sleep quality, mood, cognitive performance, even their metabolic

[5] http://www.aal-europe.eu.

Fig. 3 Smart home prototype: Aware Home Research Initiative (AHRI) at Georgia Institute of Technology [24].

Fig. 4 Smart home prototype of mavHome project [25].

system, especially to the people with chronic disorder and vision impairment. This system enables the citizen with mobility or other disability to operate environmental systems and devices directly without moving physically to the actuator's location. It allows the user to control the devices by looking directly by gaze-based interaction [26].

iDorm is one of the pioneering smart home research projects in Europe. It is established by the Intelligent Environment Group of Digital Lifestyle Centre at the University of Essex in the UK in 1999 [31]. This continuous project has been upgraded to iSpace and has become an excellent seed-bed for intelligent environment studies. The iDorm is a multi-use (sleep, work, entertaining, and study) intelligent inhabited environment equipped with different normal furniture and embedded sensors. The space contains three types of embedded computational components:

- *Physically static computational component within the building*: It has embedded agent to receive sensor data through the network, to learn the user's behavior and to make decisions for the control actions.
- *Robotic agent*: A mobile service robot agent with features like adaptive navigation, communication with static embedded agents via wireless network.
- *Portable computational devices*: Wearable sensors and PDA for wireless interaction with the iDorm.

The system of iDorm is based on an incremental synchronous learning architecture and fuzzy logic controllers (FLC). Each FLC forms a behavior, while dynamic behaviors learned from users and fixed behaviors by pre-defined programmes. FLCs are suitable for complex and dynamic lifelong learning of user's behavior. For the agents, they communicate with each other by exchanging XML-formatted queries within the network.

RoboCare [32] by ISTC-CNR is prototype of integrated home environment named RDE (RoboCare Domestic Environment) with cognitive support to improve the everyday life of older people at home. The RDE is a distributed multiagent system in which coordinated operation of agents provide various services:

- *A mobile service robot*: Robotic service is the key feature of RoboCare.
- *Interaction manager* (*IM*): The service robot acts as a cognitive mediator in the system, which can interact with users and internal algorithms, and this interaction process is controlled by the IM. The IM has two submodules, speech synthesis module (Lucia) and speech recognition module (Sonic). These two modules allow user to interact with the robot via speech.
- *People Localisation and Tracking (PLT) agent*: PLT service is based on a stereo vision sensor. This consists of the following three submodules: (1) Background modelling module, background subtraction and foreground segmentation for foreground people and objects detection. (2) Plan-view analysis of position and appearance models. (3) Tracking module for observation over time maintaining association between tracks and tracked people or objects.
- *People posture recognition (PPR) service*: PPR agent relies on the person-blob obtained by PLT and defined 3D body model. It is capable of distinguishing several major postures, such as "standing", "sitting", and "laying", etc.
- *Activities of Daily Living (ADL) monitor*: The purpose of ADL is to analyse and schedule tasks and behavior in the system. A schedule management environment is developed for ALD, in which the schedule representation is based on a temporal constraint network (TNC).
- *Personal data assistant (PDA) agent*.

As the RoboCare system combines various distributed agents to assist the user's life. It requires coordination service to manipulate the multiple agents. To deal with the coordination, ADOPTN, an extension of the ADOPT (Asynchronous Distributed Optimisation) algorithm is utilised.

PERSONA [33] is a collaborative AAL project for the ageing society founded by EU with 12 partners from Italy, Spain, Germany, Greece, Norway and Denmark (Fig. 5). It aims to develop sustainable and affordable solution for the independent living of senior people with AAL technology. With regard to the need of elderly independence, the project is divided into four categories:

- AAL services supporting social inclusion and experience exchange.
- AAL services supporting older users in their daily life activities.
- AAL services supporting older people to feel more confident, safe, and secure, and helping their relatives to manage risky situation.
- AAL services fostering mobility and supporting older people outside their home.

A scalable open Distributed System (PERSONA platform) for supporting context-awareness of AAL space was developed as a result of this project. The platform provides a middleware that supports seamless connectivity and seman-

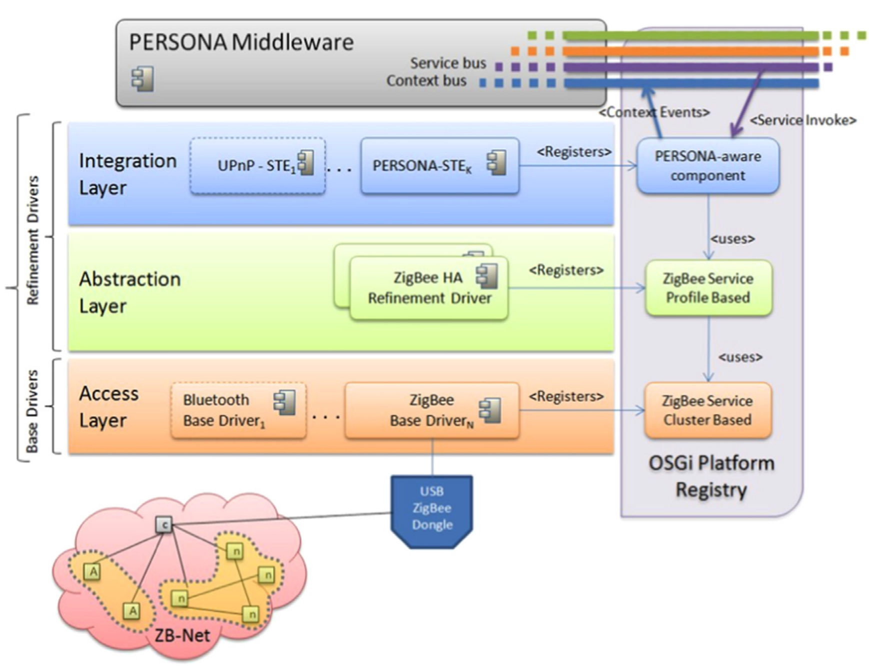


Fig. 5 Summary of PERSONA context awareness framework for AAL [33].

tic interoperability for self-organisation of physical and logical architecture. It also allows re-configuration of platform components such as the Situation Reasoner, the Dialogue Manager, and the Services Orchestrator. The architecture of PERSONA platform is composed of the following components:

- Interoperable framework provides an event-based class of buses and a call-based service for communication and specification of context.
- Some of the services in the PERSONA platform:
  1. Dialogue Manger (DM) for handling the system-wide dialogues and hiding the complexity of utilising the application service from user.
  2. Context History Entrepot (CHE) for gathering the history of all context events and guaranteeing the essential support to reasoners.
  3. Situation Reasoner (SR) that uses the database of CHE and infers new contextual information with RDF and SPARQL.
  4. Service Orchestrator (SO) for interpreting the metadata, describing a composite service and performing the instructions within it.
  5. Profile Component for guaranteeing the adaptability of the AAL system and managing the user profiles.
  6. Privacy-aware and Security Manager (PISM) for controlling the access to services in the middle-ware.
  7. AAL-Space Gateway for remote accessing to the hosted service with a fixed URL.
- The middle-ware has three layers: The Abstract Connection Layer (ACL) is the lowest layer which responses to the peer-to-peer connectivity between the middle-ware instances. The second layer, the Sodapop layer implements the peer and listener interfaces from ACL and registers as the local peer to all connectors found. The top layer is a PERSONA-specific layer, which implements the input, output, context, and service buses with distributed strategies using an RDF serializer for the exchange of message among peers.
- The Ontological Model provides a framework for sharing knowledge and resource handling within the distributed system. Three elementary tools based on ontology are developed in PERSONA platform: the knowledge representation technologies of the Semantic Web consist of RDF and OWL; an upper ontology with appropriate programming support consisting of those concepts that all users of the middle-ware used; a general conceptual solution with a certain set of shared tools for integrating thin devices and embedded sensors, and transforming the tapped data into an appropriate ontological presentation.
- Sensors Abstraction and Integration Layer (SAIL) for sensing the environment and user is composed of stationary, portable and wearable components. Wireless Sensor Network (WSN) is applied for sensing tasks. Within PERSONA, a ZigBee based network is developed to integrate and handle the WSN and other sensing components [33].

2.2. Healthcare and rehabilitation

Health plays a major role in the life of older people suffering from chronic diseases like diabetes, dementia and the other cognitive or physical impairments. Simplifying the treatment of those diseases not only eases their everyday life, but can also increase their personal safety by ensuring automatic alarms in case of a deteriorating health status. Living alone often causes fear of having an accident and being unable to call for help. This includes falls, accidents in the kitchen, but also general safety e.g. when leaving the home. It is therefore important to provide the elderly with tools, which support them regarding these issues and which, in case they cannot call for help on their own, automatically call for assistance.

With declining support from families, society will need better information and tools to ensure the well-being of the of the growing number of elderly citizens. It has been a burgeoning area of investigation in the wake of advances in in-home technology to enhance the health and independence of older adults without the constraints and expenses of the traditional health care system. Advances in health and communications technology come at a time of dramatic worldwide increases in life expectancy and skyrocketing health care costs. Home monitoring and assistive technologies are employed to identify changes in health and behavior in home settings, and to facilitate successful adaptation to those changes. This section concludes some paradigms of healthcare application in AAL (Table 1).

Kameas and Calemis [34] have surveyed a collection of pervasive systems in supporting activities with health significance. The @Home system can provide service to remotely monitor patient's vital parameters like ECG, blood pressure and oxygen saturation level. The HEARTFAID system is a knowledge-based platform that can improve early diagnosis and medical-clinical management of heart diseases. The system provides services such as electronic health record for easy and ubiquitous access to heterogeneous patient data; integrated services for health-care professionals, including patient tele-monitoring, signal and image processing; alert and alarm system; clinical decision support in the heart failure domain, based on pattern recognition in historical data; and knowledge discovery analysis and inferences on patient clinical data. The CHRONIC (An Information Capture and Processing Environment for Chronic Patients in the Information Society) project aimed to develop an integrated model for the care of targeted chronic patients in Europe.

The iCarer project [35] aims at supporting the informal care of older adults to deliver inter-operable solutions providing a holistic cloud-based care support service (Fig. 6). This includes Tunstall's lifestyle monitoring services (ADLife), enhanced to provide informal caregivers with the information required to support them in their care duties. Additional services include a personalized support and training program based on e-Learning methods, assistance mechanisms for the caregiver and monitoring and assistance services for the person being cared for. These services combine in order to achieve an overall feeling of safety and a substantial stress reduction for the caregiver.

In [36], an integrated lifestyle management system is proposed to record the user's daily health status parameters and activities for health support. The system has three layers, information gathering, information processing, and information presentation, with the following components:

- The Data Gathering Agent (DGA) collects data from various input sources. The input source can be the devices used by the user such as mobile phone, GPS, IMU, Alive Heart Monitor [37], and PC activity Platform.
- The Data Transformation Agent (DTA) operates on the input data available in differing formats and in multiple local storage locations: such as data conversion, data clustering, filtering, sorting into a user database, data optimization and Database Model Management.
- The Information Agent is responsible for processing the data collected in the central database through the information model.
- The Presentation Agent contains the role of assembling information into a story format, according to the Story Model.
- The User Interface Agent is used to create various information visualizations.
- The Policy Agent performs as a manager of policies related to information usage, as well as various user preferences, and will become increasingly important once external parties are added to the system.

This system can not only provide monitoring of health status with specific parameters, but also reflects the reason of "what happened".

The Home Healthcare Monitoring System (HHMS) supports older users' daily health-care and their quality of life by collecting relevant medical and daily routing data. The data is gathered into a Healthcare Management Information System (HMIS) for physicians in hospital to diagnose. A interoperability Mediation System was proposed in [38] which acts as a bridge between HHMS and HMIS. HHMS collects information in raw sensoray format and stores in XML format while HMIS follows standard structure of

Table 1 AAL for health, rehabilitation and care [8].

AAL service	Level 1	Level 2	Level 3
Self-management of chronic diseases	Intervention of the patient for powering and management of diseases	Patient part of the care team, integrated processes	No patient intervention for powering and management of diseases
Chronic disease management	Telemonitoring, remote consults using audio and low resolution video	Integration of services at care delivery organisations, link to non-healthcare services, fitness and activity management	Cross institutional integration, supporting integrative care models
Medication management	Reminder system with monitoring of medication intake	Extended with educational and motivation for the patient and medicine interaction check	Integrated into disease management
Rehabilitation	Monitor exercises in home situation using wearable sensors	Support and monitor exercises with operational devices at home	Support and monitor exercises with exoskeleton-like devices using advanced neuro-scientific control models
Care team support	Stand-alone services like tele-monitoring, tele-consultation, medication management, activity management	Integration of services at care delivery organisation, link to non-healthcare services like fitness and activity management	Cross institutional integration, supporting integrative care models and non healthcare services

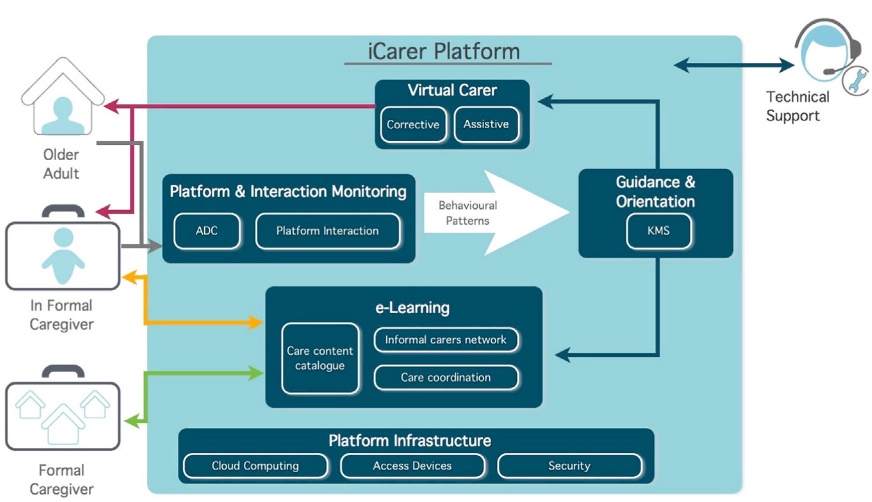


Fig. 6 Architecture of iCarer system and services [35].

information based on its compliance with the health-care standard. In their system, a HARE (Human Activity Recognition Engine) is developed to monitor the activities of Alzheimer disease patients. Clinical Document Architecture (CDA) markup standard is used to specify the structure and semantics of “clinic documents” from the sensors data gathered, processed, and then filtered as part of CDA documents.

In [39] Corchado et al. developed the GerAmi (Geriatric Ambient Intelligence), an intelligent environment that integrates multiagent systems, mobile devices, RFID, and Wi-Fi technologies to facilitate management and control of geriatric residences. The system was evaluated to reduce task time with Nurse agent and Doctor agent, provide patient care by enhancing the communication between patients and hospital staff, facilitate security monitoring patients and guaranteeing that each is in the right place, storing information more securely.

Quality of sleep is an important attribute of a senior person's health state. The sleep pattern is a significant aspect to evaluate the quality of sleep. An automatic sleep monitoring system for home health-care is presented by [40]. In this system, the sleep data can be collected by sensor board and transmitted to data centre in real-time and continuous mode. A web-based application is used to visualize sleep data. It also provides algorithms to produce user's sleep qualities and health patterns by analysing the sleep data.

Safety risks are the most often-cited reason for people having to leave their homes for supported living environments. According to the caregivers, wheelchair users tend to fall down from their beds or their wheelchairs when they transfer between the bed and the wheelchair or between wheelchair and toilet seat. It is also likely that older people who suffer from senile dementia tumble from their beds when they try to sneak out of the bed. Pivato et al. proposed a low-cost wearable WSN node for body detection [41]. Their project was resulted in an ultra-light and easily wearable device for both fall detection and coarse-grained RSS-based localisation, while keeping lifetime as long as possible.

Diabetes Support Systems usually record blood glucose measurements, time stamps as well as information related to administering insulin. A diabetes support system in AAL is described in [42]. The service value network (SVN) approach is applied to automatically match medical practice recommendations based on patient sensor data in a home care monitoring context to health services provided by a network of service providers. The system is demonstrated with an SVN composition based on an initial set 493 patient profiles in the context of Type 2 Diabetes management.

Memory decline is a highly debilitating condition for many seniors, especially for those with dementia. There have been many applications within the area of AAL that are relevant to older adults with cognitive impairments [7,43,44,9]. Automated Memory Support for Social Interaction (AMSSI), a system proposed by Bellodi et al. [45], helps memory impaired people with their social interaction. This system provides active support that may help reducing stress level of patients. It can recognize visitors, determine the purpose of the visit, monitor the dialogue, determine whether the patient needs support, and provide feedback. AMSSI is tailored to patient needs, it has fast computation, full automation, and can be handled by the patient without supervision. The assistive system can be beneficial for improving the quality of life of patients with mild to moderate cognitive impairments.

Paper-based Early Warning Scorecards (EWS) are widespread in hospital for clinical decision support. They are designed to help clinicians identify the patients who are most at risk of suffering an adverse event in advance. A scorecard is a reference table which associates individual vital signs parameters (e.g. heart rate, respiratory rate, etc.) with a score (0, 1, 2, or 3), which is representative of the physiological derangement from a normal range. But sometimes hospitals and caregivers experience delayed recognition of the deterioration and this leads to late referral to critical care, even some cases death. An Electronic-Early Warning Scorecard proposed in [46] has demonstrated its significant efficiency and usability over paper-based EWS with a sensor based network health monitoring with context awareness.

2.3. Mobility assistance

Mobility is significant component to quality of life as it allows a person to independently move about when and where he or she intends to go. Many people with motor disabilities and cognitive impairments often encounter various barriers in their daily life. They invalidate the ability to perform movement to a desired destination and certain tasks. This limits the capacity of operating devices, manipulating objects and mobility. As a result, a considerable part of the population with motor impairment must rely on assistance from others to get from place to place. Mobility support ranges from assistance with planning routes and navigation from one location to another safely without human intervention.

The research of smart wheelchairs emerged since the early 1980s over the world to accommodate these people [47]. Assistive robotics technologies have been applied to develop smart wheelchairs that can provide navigation assistance. Such wheelchair typically consist of electric powered wheelchair or scooter with computer attached sensors and actuators. Since the 1990s, several long-term projects were established to develop appropriate wheelchairs for motor disabled people. VAHM [48] is a EU project from 1989 to 2002, an agent based smart wheelchair was developed in the project. The NavChair [49] is an advanced intelligent wheelchair developed in a project from 1990 to 1999. The collaborative shared control architecture prototype was proposed in NavChair and this significant architecture was employed widely in many intelligent wheelchairs [47]. SENARIO [50] wheelchair is developed in a EU founded project. It can provide shared-control navigation (obstacle avoidance) and autonomous navigation based on a pre-built map. Neural networks are used for localization, and distributed control architecture in SENARIO. The Wheelesley [51] project (1995–2002) at MIT employed machine vision for obstacle detection, which allows wheelchair to travel safely outdoors as well. PerMMA [52] is composed of a robotic powered wheelchair and two arms to provide enhanced mobility and bi-manual manipulation for people with lower and upper extremity impairment (Fig. 7).

Fig. 7 Examples of intelligent wheelchair prototypes. (a) NavChair, (b) Wheelesley, (c) VAHM and (d) PerMMA-wheelchair.

However, hitherto there are few intelligent wheelchairs that are widely sold commercially, most of them are still in laboratory for research use since it is too expensive and seldom affordable to citizen. Many ongoing research projects [53-57] aim to reduce the cost of intelligent wheelchairs and enhance the capabilities of the wheelchairs with higher "Intelligence".

Besides wheelchairs, some other innovative personal mobility devices such as Nosegay vehicles [58], Mecanum wheel vehicles [59], Hybrid Assistive Limb (HAL) [60], intelligent mobility scooter [61], smart tricycle [62] and smart vehicle are investigated by the research communities. These robotic products will be significant to accommodate the population with mobility barriers (Fig. 8).

2.4. Social inclusion and communication

Another important mission of AAL service is to prevent social isolation. Social interaction and communication are factors that have remarkable influence on the quality of life. As an individual, interacting with others and taking apart in social activities and entertainment are essential elements of enjoyable life. Traditionally, people can get to communicate with their families and friends via phone, email, internet based communications etc. Television, newspaper and the internet are typically the main media to access social information and entertainment. However, many older people with cognitive/physical impairments have obstacle to access the social media and participate insocial activities. Whence AAL technology aims to engage the elderly to stay happy in their living environment, remain active in their community, and have contact with their community [63].

GENIO [64] is an AAL application in home automation. It is endowed with functions such as reading e-mails, programming washing machine, checking the goods in the refrigerator, creating a shopping list, doing shopping with a PDA in a supermarket, activating the dishwasher, being guided on how to prepare a recipe for the oven and checking if there are the needed goods to do so, listening some music stored at home, watching some photos, watching some selected video and so on. The users can dialogue with the system through a microphone attached in their pocket.

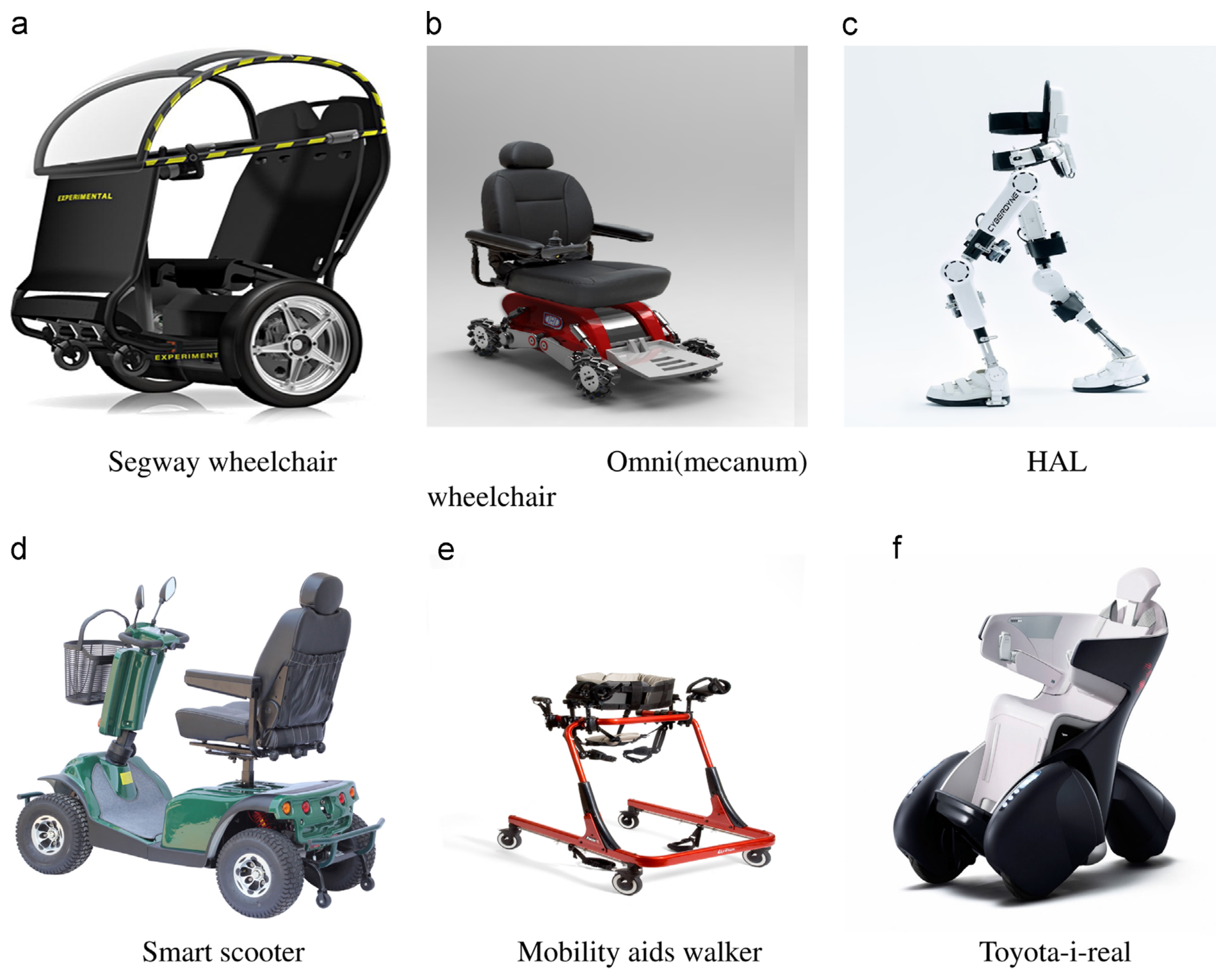


Fig. 8 Mobility assistance equipment prototypes. (a) Segway wheelchair, (b) Omni(mecanum) wheelchair, (c) HAL, (d) Smart scooter, (e) Mobility aids walker and (f) Toyota-i-real.

The aim of Building Bridge Project [66] is to applied communication technology to enhance social connection for the older with their peers, family and friends. The device can provide older people with the opportunity to connect with their family and friends through the shared experience of a video or radio broadcast (such as documentaries, news, and health bulletins). Following each broadcast, listeners have the option to take part in a group chat. Further functionality includes individual or group calls, a (textual) messaging service, and most recently a tea room which represents a chat forum (Fig. 9).

A domestic communication designed within NETCARITY (EU FP6) project aimed to provide services that foster social contact and strengthen social ties within the social network of elderly people living alone [67]. The project proposed a prototype of e-inclusion: a user interface that exploits touch-screen technology, whereby interaction is based on the direct manipulation of the digital objects, using natural gestures recalling real world motor patterns.

The HOST project [65], a smart technology for self-service to seniors in social housing, is a part of the EU AAL Joint Programme. It aims to provide solutions to the needs of Social Housing requirements today, in order to enrich the life of the elderly living in the current social house park with a comfortable and friendly context to enable the integration of older population into a self-serve society. These competences of social hosing allow a better quality of communication and a better access to package services from the elderly; enable easier relations with, family, service providers and housing operators, through enriched supports (images, text, voice, documents) (Fig. 10).

3. Instrumentation and platforms

3.1. Appliances and sensors for AAL

A smart home is a daily living space with various types of sensors and actuators installed, in order to monitor activities and control appliances in the space. Sensors and actuators are the main components that cannot be absent in a smart home. The sensors are used to measure the temperature, light intensity in the environment or sample the biological signals from the users. This actively obtained information is used as the inputs of a smart home system, so a user does not need to manually input them. The actuators are used to perform user's repeatedly or predictively

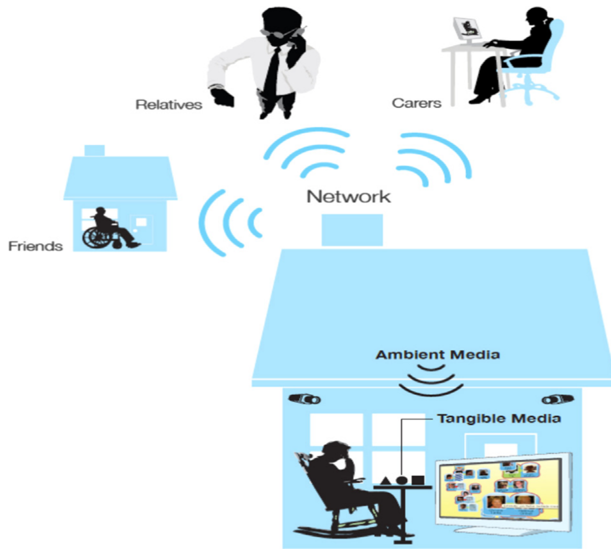


Fig. 9 Social Inclusion Services for assisted living [35].

actions, like turning on/off appliances opening/shutting a door, etc., which adds autonomous features to the system.

In a typical smart home, the devices/ appliances are summarised below [68]:

- *Sensors*: RFID tag, physical presence sensor, positioning sensor, health monitoring detector (body sensor), accident detector, video camera (CCTV or private camera);
- *Household appliances*: Refrigerator, washing machine, lights, bed, door, TV, computer, cleaner, air conditioner, kitchen appliances etc.;
- *Actuators*: Door open/closing actuator, window open/closing actuator, air-conditioning actuator, light actuator, home appliances switches;
- *Security*: Password lock,voice pattern lock, Biometric verifier (fingerprint reader, iris scanner);
- *Communicate*: Network, smart-phone (watch, camera), human machine interfaces.

There are various wearable health monitoring devices currently on the market such as 9Solutions IPCS, Health Buddy (Bosch), Telestation (Phillips), Genesis DM (Honeywell), Health Guide (Intel), LifeView (American TeleCare), Ideal LIFE Pod (Ideal Life), Healthanywhere (Healthanywhere Inc.), Respiratory Rate Detector [69] and Smart cloth [70-72]. These systems are able to take physiological readings (e.g. blood pressure, heart rate, temperature, glucose levels, calories etc.) using conventional measurement devices (e.g. blood pressure cuff, thermometer, blood glucose meter, location etc.) and share them remotely with clinicians [73].

In many smart home prototypes, the typical appliances (bed, lights, bathroom, TV, fridge, cook stove, etc.) are designed particularly for the older or disabled for convenient and safe access. For some cognitive impaired people, it may lead to fire risk if they forget to switch off the stove and leave a pan on it. A stove guard kitchen monitor is presented in [74]. The monitor is mounted on stove to avoid the risk of fire. Another smart kitchen system for AAL is described in [75], which integrates a wide variety of home technologies (household appliances, sensors, user interfaces, etc.) and associated communication standards and media (power line, radio frequency, infrared and cables). The system is based on the Open Services Gateway initiative (OSGi), which allows building a complex system composed of small modules, each one providing the specific functionalities required, and is easily scaled to meet our needs.

The Robotic Bed [76] is sleeping system equipped with a wheelchair-like control system. It enables the user to steer easily and to change between the wheelchair and the bed. In the wheel chair mode the robot is able to recognize people and obstacles in order to avoid collisions and to navigate safely. In the bed mode, it supports the posture by adjusting and optimisation the mattress form. Intelligence Toilet [76] in Daiwa House & Cyberdyne is a toilet system, which is able to measure the sugar level in the urine, and also the blood pressure, body fat and weight. These features should facilitate the user to avoid forthcoming illnesses by early diagnosis and reduce medical inspections at a doctor's office.

Many of these devices allow the person being monitored to interact with clinicians over video screens, enabling more personal communication. Some also have access to online, multimedia educational materials, caregiver networks, and other resources that can help people to manage conditions. These tools can be valuable for caregivers and clinicians who are managing the health of older adults with dementia living at home. With the help of these sensors and actuators, a smart home is then able to analyze the requirements of people that having cognitive impairment, and support them living better on their own.

With further processes, additional information could be acquired beyond the sensor was originally designed for. For example, WLAN (wireless local area network) is a common basic communication framework in a modern building. Besides its normal communication usage, a location tracking application is possible to be implemented by calculating the distances of mobile devices to each network access point. In this design, the advantages are no additional localisation devices are needed and it can work indoors. The difficulties usually are caused by the complexity of environment (walls, passengers and other obstacles). In order to solve this problem, [77] uses a back-propagation neural network to calibrate the interference from the obstacles. By combining various type of sensors, even more information could be obtained. Explicitly, cameras, temperature, light and other sensors are used to learn a user's interferences behavior in a smart environment in [27].

Based on the current development trend, we noticed that the basic sensor types are limited, smart home (environment) appliances are required to have various sensors collaborate together to provide the most information, and have standard information sharing interfaces to interact with other smart appliances.

3.2. Robotic service platforms

The next revolution in the smart home is expected to come from the world of robotics [78]. Service and assistive robotic technologies have high relevance to AAL. Robotic assistive technologies cover a range of applications helping people

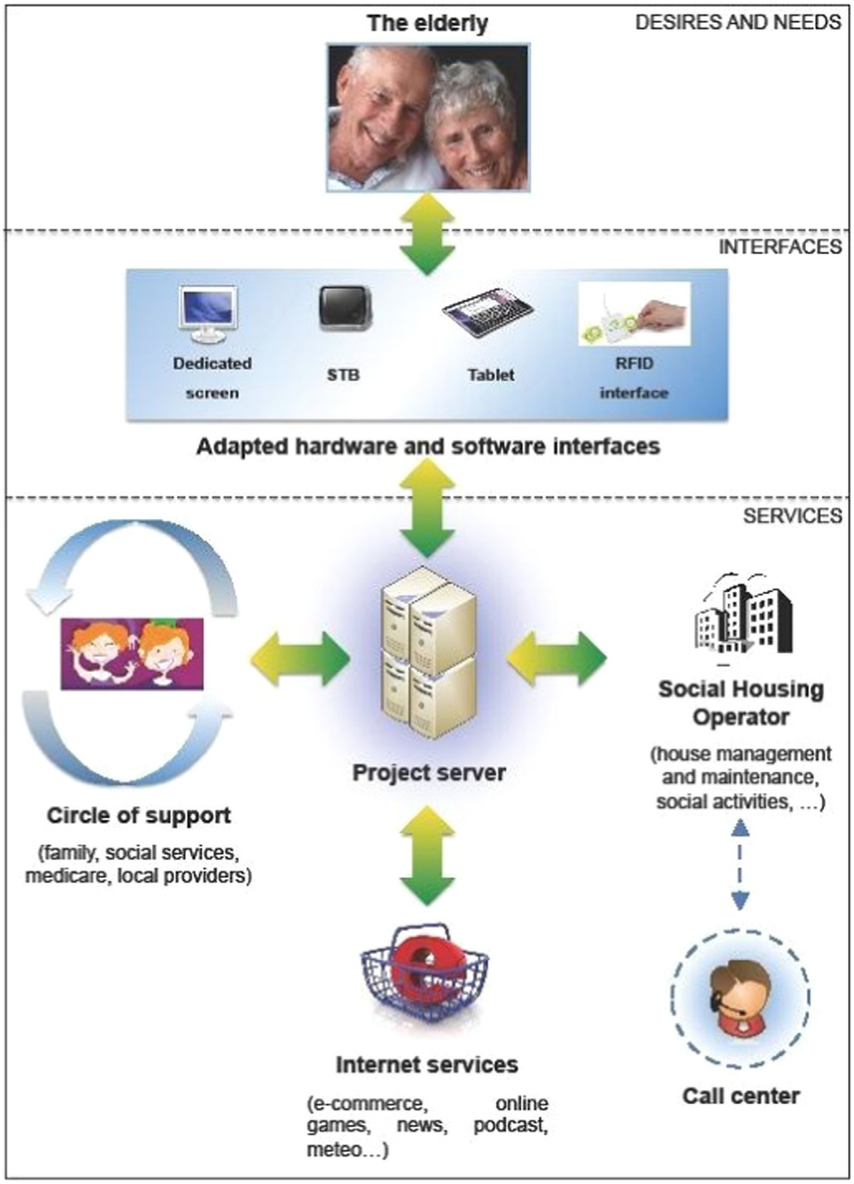


Fig. 10 Scenario of Social Inclusion Services for HOST assisted living [65].

with physical, social, and/or cognitive disorders from daily tasks to cognitive rehabilitation. For different purposes, the robotic service platforms vary from each other in mobility, size and appearance design. Ref [8] lists a rich collection of platforms for personal daily care. The most major of those recognised today include mobility, self-maintenance activities assistance, such as cooking, feeding, dressing, grooming, bathing etc. Ref [79] presents a serial of approaches to enhance the cognitive capabilities of ubiquitous robots, in order to supply users with assistive services and execute complex tasks in dynamic real world domains.

Mobility assistance is an essential service for disabled persons. Intelligent wheelchairs, guide-canes, assistive limbs and interactive walkers are developed to support mobility to the older and disabled as we mentioned in previous section.

Many elderly people have difficult activities of the daily living such as feeding, dressing, meals preparation, taking medicines and so on. Service robots provide the user with a functional assistance to deal with the difficulties encountered in daily life. As an example, Pearl robot [80] from the Carnegie Mellon University is one of the most-cited and studied robots which provides routine activity reminders (eating, drinking, taking medicine) as well as some walking guidance. The interaction is realized through speech synthesis, visual display onto a touch screen, and motions of an actuated head unit. Other relevant systems are the Care-o-Bot [78], the Cero [81] robot, PR2 robot and the ROBOCARE [28] (Fig. 11).

Besides, as the health of a person is closely related to the quality of life. With the age growing, elderly people are more likely to rely on nutrition supplements or drugs for senile diseases. Medicine service robots should be capable to remind the user and monitor the drug intake information. Some robots are designed to maintain proper diet, exercises, health monitoring and check up or monitor health parameters. MINAmI was a project working on interacting tiny AmI environmental sensors with a mobile phone. One of

Fig. 11 Some domestic assistant robots for commercial and research.

their targets is to provide supplement safety and health services for older people. As a part of this research, a similar drug service platform is described in [82].

A robot exercise coach presented in [83] is able to train physical exercise for the older population. Its built in workout game, sequence game, imitation game, and memory game help the users with cognitive impairment and engage them in participate in social activities.

A robot might be employed for security and emergency intervention. Such a robot is able to monitor home and upload sensor data to the server and identify risks. In the case of an emergency situation such as detected fall, a mobile robot has the advantage that it is able to move towards a person. The robot can talk to the person first, and then take a picture, send it to caregivers and initiate an alarm. Furthermore, the fallen person could call the robot for help. The robot can directly contact the user and initiate a call to family members or caregivers [84].

To help and ease the living of the cognitive impairment older people, companion robots are being investigated by various institutions. A robotic baby seal (Paro) is being developed at AIST (The National Institute of Advanced Industrial Science and Technology, Japan). From their experimental results in [85], it is proved that Paro actually brings happiness to the elderly people with different levels of cognitive impairment (evaluated by counting the smiling/laughing times during the experiments). More theoretically, the interaction mechanism between companions (animal or robotic companion) and humans is being investigated at the MIT Media Lab. To test the corresponding theory framework, a robotic Teddy-bear is constructed. Based on how the animal or human skin is designed, [86] investigated the usages of various types of sensor (including temperature , pressure, etc.) to construct the "sensitive skin ".

Instead of discussing the technical details, [87] studies the potential psychology theory between human and robots. It points out that the recent robots can be classified into two major categories according to their applications: assisting robots and interactive simulation robots. Assisting robots aim at increasing the working productivity or finishing the jobs that are impossible for humans. In contrast, the interactive simulation robots focuses on providing social, educational or entertainment services with immersion and realistic experiences. The later category is the major object of the human–robot psychology research. In this research, the interaction between human and robots is organized in a Complex Interactive System (CIS) and multiple dimensions of communication effects are discussed and analyzed. Particularly, a robot cat (NeCoRo, Omron Corp. [88]) is used as the research object while Person–Robot Complex Interaction Scale (PRCIS) [89] is used as an assessment tool.

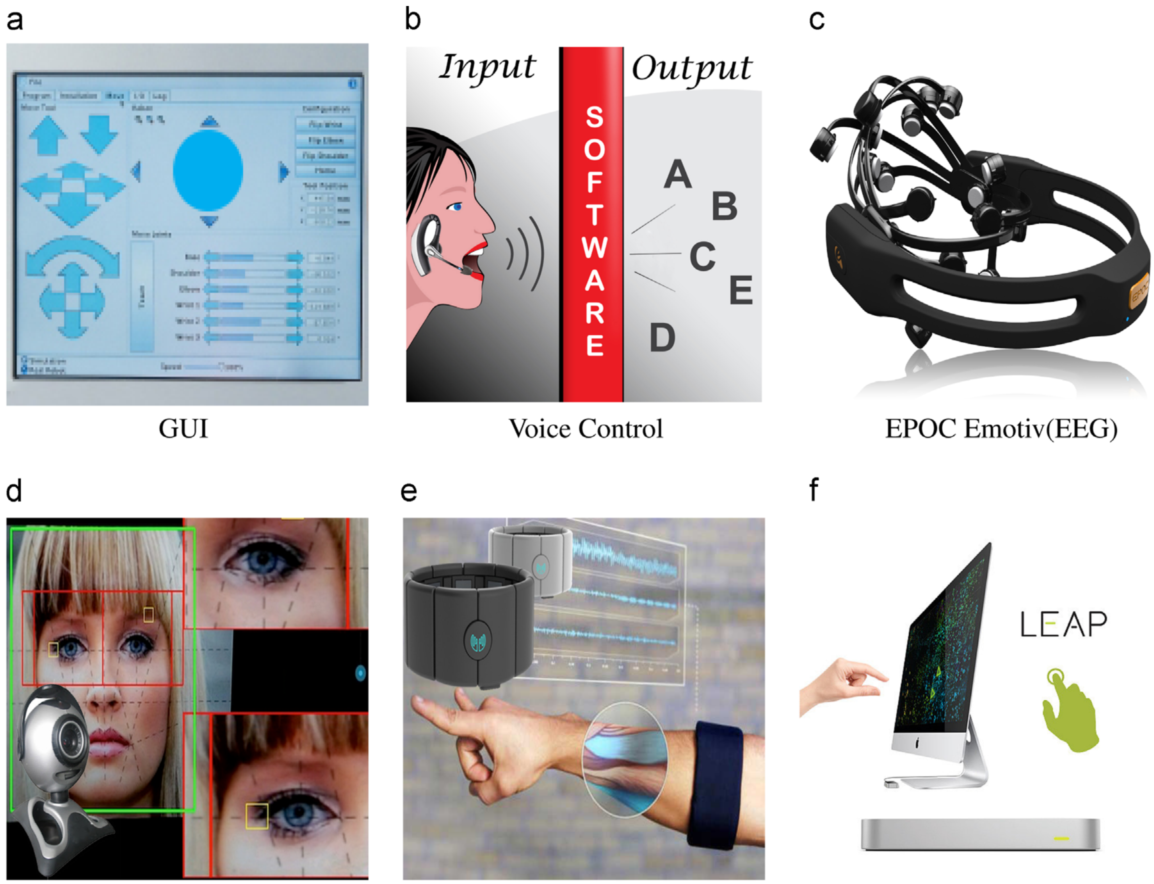
The research in domestic service robotics concerns Self-organizing brains, Human–Robot-Interaction and Cooperation, Navigation and Simultaneous Localisation and Mapping (SLAM) in dynamic environments, Computer Vision and Object Recognition under natural light conditions, and Object Manipulation. All these challenges involve vast area of research subjects and disciplines.

3.3. Human machine interfaces

Various smart device technologies are steadily penetrating our daily lives. We are surrounded by these products and interact with them in many ways. Particularly, such devices may potentially improve the quality of life of older people and patients with impairments. Applications of daily living assistance require robust interfaces that allow for natural control. These interfaces may rely on diverse modal information that can be related with the intention, preparation and generation of voluntary movement, either at mechanical or neural level. To have the smart environment work more pervasive and easier to access by elderly people who usually do not have much knowledge on operating complex computer systems, the human machine interfaces (HMIs) largely determines whether the smart homes are acceptable by elderly users (Fig. 12).

Instead of using traditional keyboards and mice, natural interaction approaches between human and machines (robots) are investigated in both academia and industry. Some relatively mature techniques include using joystick and touch pad/screen. Compared with the keyboard/mouse commands, these methods provides a more intuitive interacting experiences.

In order to provide immersive using experience, voice and vision controllers are widely employed. Since the experience using these is more close to the interaction between humans, it is more natural and effective. In the voice control research, voice recognition is well researched and the difficulties remains in the natural language processing (NLP). The target of NLP is finding the approaches to have machines understand human languages. Vision interaction is a relatively wider research field, it contains various topics and each of them has the great potential in different scenarios. For instance, an eye-blink monitoring system is proposed in [90], a vision 3D automatic microassembly system is presented in [91], and a thermal-based human tracking system that can localise users is reported in [92]. Except for the traditional camera based methods, more powerful cameras with depth information are being developed and used for research in recent years, such as Kinect [93] and Leap Motion [94,95]. Due to the depth information obtained, more control strategies are able to be developed



GUI
Voice Control
EPOC Emotiv(EEG)
Computer vision based Control
Myo gesture control(EMG+IMU)
Leap motion gesture control

Fig. 12 Examples of human machine interface. (a) GUI, (b) voice control, (c) EPOC Emotiv (EEG), (d) computer vision based control, (e) Myo gesture control (EMG+IMU) and (f) leap motion gesture control.

with better accuracy. Specially, biological signals are one of the solutions for pervasively receiving commands from human. Widely investigated biological electro signals include EMG (Electromyography), EEG (Electroencephalography) and EOG (Electrooculography) [96].

4. Monitoring and communication infrastructure

Typically, AAL environments are composed by different kinds of devices such as mobile phones, embedded devices, and wired or wireless sensors. Although nowadays there are raising some efforts raised based on communication standards for tele-medical devices, its adoption is going slow. In addition, both biomedical and user devices often run on different network protocols which obstruct a real integration between the devices. Smart sensors have been a breakthrough in the applications of monitoring mobile objects or individuals. On this basis, smart sensors are becoming a main "role " on AAL environments. Thanks to the protocols and standards of sensor network technology, the heterogeneous devices are able to communicate and process the information between a smart home and users.

4.1. Some standards of communication for AAL

WSNs are an important technological support for smart environments and ambient assisted applications. A WSN consists of hundreds or thousands of sensor nodes that have the ability to communicate either with each other or directly with the base-station. A base-station is a fixed node or a mobile node that is capable of connecting the sensor network to an existing communications infrastructure or to the Internet. At a higher level, WSNs can be modeled as a distributed database where every node is a database. The attributes of database are the types of sensors mounted on the node. A user can query the database (node) to retrieve the values of attributes of interest, such as pressure, humidity, temperature, longitude, latitude, etc.. Due to the embedded, distributed, pervasive and other features that commonly required in AAL projects, a series of suitable communication standards are usually chosen as the guide for developing smart environments. Some of the important ones are organised below [97]:

CORBA: Common Object Requester Broker Architecture (CORBA) is a standard for enabling software modules, written in multiple languages and run on different computers, to work together. Additionally, CORBA provides a strong data-type between different languages to reduce human errors, encapsulates data-transfer and other low level technical details to enhance the robustness, and makes the system development more convenient. Therefore, this standard could be considered as the foundation of developing distributed systems.

UPnP: UPnP (Universal Plug and Play) is a group of protocols or a much-extended architecture suggested by Microsoft (Olleros 2007) and promulgated by the UPnP Forum, which ensures that some network devices can autoconfigure. The aims of UPnP are making sure that the devices can connect perfectly and simplifying the implementation of networks at home (exchange of data, communications and entertainment) and in corporate environments. It is an open and distributed architecture based on already existing protocols and specifications, such as UDP, SSDP, SOAP or XML. In order to simplify the installation and connection between any two devices in a distributed network, the UPnP is promoted as a set of networking protocols. This protocol set allows the peer-to-peer connection between devices, which is a distributed architecture based on various established protocols such as TCP/IP, UDP/IP, and HTTP, etc. As a instance, ALL applications in [98,99] employed UPnP to integrate robot and sensors to the digital home.

Jini: Jini is an architecture similar to UPnP. By using which, a device can announce its presence to the network together with its services as soon as its connected to a network. Compared with UPnP, both of them are designed for the "plug and play" feature, but UPnP focuses more on managing devices in the network while Jini concentrates on discovering and providing services [100].

WS (Web Service): WS is usually used as a supplementary technique to the previously mentioned standards. The main highlight of this standard is that the standard text-based HTTP is used and it can compatibly run on different platforms. However, due to the overly complex package header (this requires fragmentation frequently), the text-based function calling approach cost higher run-time resources. Additionally, WS can easily penetrate the firewall, which provides convenience on communication but also introduces security problems. To solve these problems, [101] proposes the embedded web services.

4.2. Communication techniques in current AAL projects

Internet of things (IoT) provides connectivity and intelligence to convert small devices and common things into smart objects. The IoT describes a world where machines and physical objects are seamlessly integrated into the information network, and communicate together to exchange and process information.

The smart objects present high capabilities to integrate and transfer enriched data from embedded sensors, activities, behaviours and clinical devices from mobile health and smart environments. AAL with IoT technology can facilitate disabled people with the assistance and support they need to achieve a good quality of life and allows them to participate in the social and economic life. Assistive IoT technologies are powerful tools to increase independence and improve participation. Smart environment projects presented in [102-105] provide some instances of IoT for AAL.

For example, in [102], communications among devices are categorised into two groups: LTE-based indoor communication and short-distance wireless communication. The LTE is also known as the 4G mobile network which provides better data capacity. While using the 20 MHz channel, its downlink and uplink can reach to 100 Mbps and 50 Mbps. This makes the data bandwidth sufficient for connecting mass number of devices simultaneously. The short distance wireless communication techniques include Bluetooth, RFID, WiFi, and Zigbee. From the analysis in the paper, it has been found that Bluetooth suffers from the communication distance being too short and the peer-to-peer communication mode, and RFID encounters poor reliability. Therefore, the usage of these two techniques are relatively limited in a smart environment. In contrast, WiFi is developing fast in the sense of its coverage area and data transmitting speed capability. Zigbee is a new type of technique with low power consuming and high reliability. Hence they are predicted to play significant roles in the future smart environments.

Compared with the traditional network communication techniques, the ones used in AAL require additional configurations with a larger address space and lower power consumption. In order to achieve this goal, [106] provides a gateway solution that can interact with IPv6 devices over 6LoWPAN (IPv6 over Low power Wireless Personal Area Networks). To be compatible with IPv4, WiFi and Ethernet interfaces are also provided. Additionally, UPnP is enabled on IPv6 to make the system easier to be configured and used.

Ref [107] provide an example of intrusion detection system, using WiFi/internet with mobile SMS (short message service). In this project, the camera information is collected from each of the cameras in different rooms through WiFi and passed to the cloud service over internet. If any intrusion occurs, the cloud will send a message to the user together with the corresponding camera streaming video. Then the user is able to make the decision, e.g. call the local police or ring the alarm.

As a conclusion, most of the existing communication techniques can find their own positions in AAL projects, depending on several criteria: installation/maintaining costs, power consumption, security level, communicating speed, etc. A balance among all these factors is the key of producing a better smart environment.

5. Theories and approaches for AAL system

5.1. Multi-agent system

Autonomous agents and multi-agent systems represent a way of analysing, designing, and implementing complex software systems. The agent-based approach offers a collection of powerful tools, techniques, and metaphors that have the potential to significantly improve the way in which people conceptualise and implement different types of complex software. Agents and multi-agent systems are being applied in an increasingly wide variety of applications

[108]. Of course, the multi-agent systems approach is widely used in support of Ambient Assisted Living in various aspects. Using a multi-agent system for the AAL environment consists of agents that represent inhabitants (humans, animals, plants, and objects) of the environment and physical devices (sensors and actuators) that control and monitor the environment. The issues involving multiple parameter optimisation and constraint satisfaction while maintaining the well-being and physical structure of the inhabitants of environment as well as the comfort of multiple human inhabitants sharing the same environment and its resources Inhabitants. An ambient agent is assumed to maintain knowledge about certain aspects of human functions, and information about the current state and history of the world and other agents. Such paradigms of agent-based AAL systems can be found from [109-113]. Here we briefly describe some instances of AAL systems which utilise agent-based approaches (Fig. 13).

The MavHome smart home project [25] focuses on the creation of an environment that acts as an intelligent agent, perceiving the state of the home through sensors and acting upon the environment through device controllers. The MavHome agent can be decomposed into multiple lower-level agents responsible for sub-tasks within the home, including robot and sensor agents, and MavHome can dynamically reorganise the hierarchy to maximise performance. Within the system, agents are separated into four cooperating layers. (1) The Decision layer selects actions for the agent to execute based on information supplied from the other layers through the Information layer. (2) The Information layer gathers, stores, and generates knowledge useful for decision making. (3) The Communication layer facilitates the communication of information, requests, and queries between agents. (4) The Physical layer contains the hardware within the house including individual devices, transducers, and network hardware.

In [115] an agent-based ambient is presented based on monitoring human's interaction with his or her environment and performing cognitive analysis of the causes of observed or predicted behaviours. Within the agent architecture, a cognitive model for the human is taken as a point of departure. From the cognitive model it is automatically derived how internal cognitive states affect human's performance aspects. Furthermore, for these cognitive states representation relations are derived from the cognitive model, expressed by temporal specifications involving events that will be monitored. The representation relations are verified on the monitoring information automatically, resulting in the identification of cognitive states, which affect the performance aspects. In such a way the ambient agent model is able to provide a more in-depth cognitive analysis of causes of (un)satisfactory performance and based on this analysis generate interventions in a knowledgeable manner. The multi-agents architecture and ontology defined permits real time environment processing and user data collected through non-invasive market sensors, installed in the home, to allow early detection and notification of potentially dangerous situation like the elderly falling.

As computers become ubiquitous, settings in which they make decisions with people over time are becoming increasingly prevalent. Many of these settings require computer agents to generate advice to their human users about which decisions to take in a way that guides their behaviour. Such settings arise in a variety of application domains such as hospital care-delivery systems, negotiation training or route-

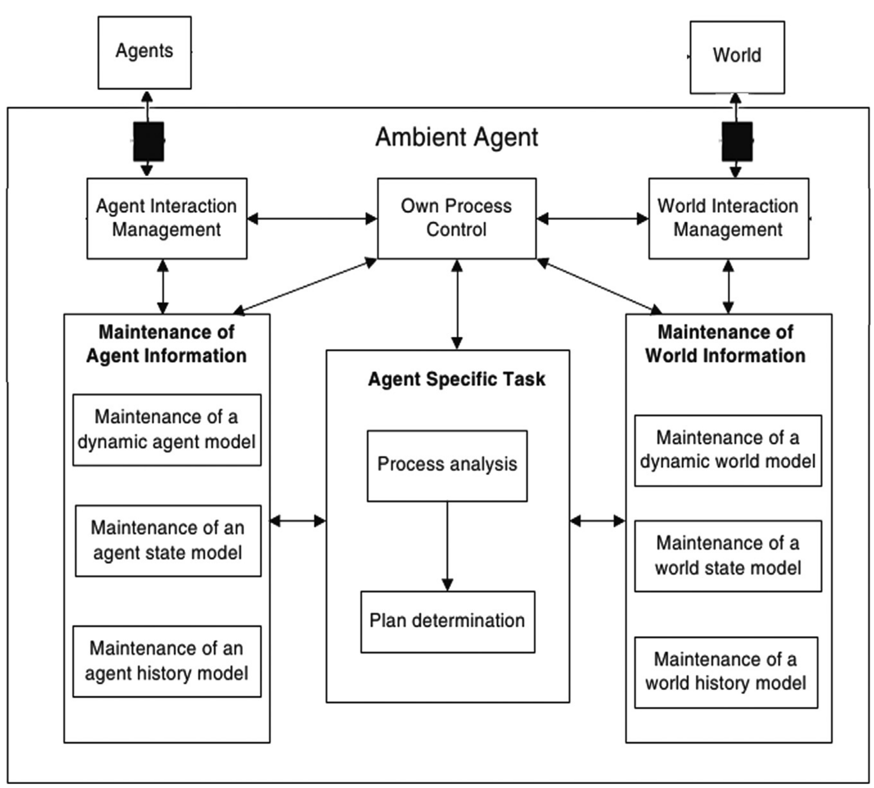


Fig. 13 An example of multiagent system for AAL [114].

navigation systems. Although computers and people in these domains share some goals, such as completing the user's tasks, their goals may also conflict. An intelligent agents reasoning platform to support smart home tele-care presented in [116] offers advice provision strategies for computer agents that interact with people in repeated settings. The models of these interactions are defined as a family of repeated games of incomplete information called choice selection processes comprising a human and a computer player. Both of the participants in a choice selection process are self-interested.

5.2. Context modelling and context awareness

Context awareness (i.e. heart rate monitoring, medication prompting, generation of agenda reminders, temperature changing, weather alerts, emergency notifications, and human emotions) is a significant feature in smart environments designed for helping elderly people living alone and independently in their homes. Activity monitoring and recognition may be useful in generating health or emergency alerts in both short and long term, possibly requiring immediate intervention, performing fluid interaction, and providing associated actions or services with regard to the dwellers behaviours, etc. This is very meaningful for helping people with cognitive and mobility impairments to promote Active Ageing activities related to communication, stimulation and environmental control [116]. In order to achieve this, a system must have a thorough knowledge of environments. We may say "understanding" of the environments, devices and people existing in it; "knowing" the interests of user, the capabilities system, the events happening, the tasks and activities are being undertaken, etc. [117].

The issues context awareness include [118]:

- how to acquire, categorise and model contextual information;
- how to exploit contexts to answer a user's data request;
- how to effectively communicate answers to the users on small hand-held devices;
- context-aware query language for users;
- what context-aware strategies are needed, both for finding useful answers to queries and for presenting the answers to the users.

To understand the behaviour of humans in the AAL environment, activity monitoring and recognition problems have to be considered, which uses data collected from environmental sensors installed in the home and wearable biomedical sensors to build a profile of the dweller's typical pattern of living and health status, such as when a person gets up and goes to bed, level and location of movement. Any variation from the typical pattern of activity may be a source of concern, for example a reduced level of activity during the day may be indicative of a decline in health status. Activity recognition algorithms can be divided into three categories: machine learning techniques [119,120], grammar based techniques [121] and ontological reasoning [122]. Many types of machine algorithms for activity recognition were developed, including Hidden Markov Models, Bayesian Networks or Support Vector Machine techniques [123,124]. Among them Hidden Markov Models and Bayesian Networks are the most commonly used methods in activity recognition. Standard Hidden Markov Models (HMM) are employed for simple activity recognition [125–127]. Moreover, Hybrid model of Bayesian networks and support vector machines is used for more accurate and faster activity recognition [128].

Expression of real world states, is related with information expression and knowledge expression. Bikakis [129] and Hiristova [130] presented various solutions that have been proposed to represent context for the AAL environment by invoking semantics-based approaches. By semantic approach, we mean ontology language and model which is widely used for the representation of context. An ontology is understood as a formal, explicit specification of a common conceptualisation. The use of ontology languages is becoming common in AAL applications mainly because they offer enough representational capabilities to develop a formal context model that can be shared, reused, extended for the needs of specific domains, but also combined with data originating from other sources. Moreover, most of them have relatively low computational complexity, allowing them to deal well with situations of rapidly changing context. These technologies simplify the reaction to various and rapidly changing needs of assisted living [131]. In accordance to the general understanding of information sciences, ontologies are composed of a vocabulary and the coherent explicit assumptions regarding the meaning of the vocabulary. For the description of the vocabulary, logic-based languages can be used with their most prominent representative, the Web Ontology Language (OWL).

In an ontology based information system, semantic-web based languages, like RDF (Resource Description Framework) and OWL (Web Ontology Language), are commonly employed to describe taxonomies and logic for context data. RDF is used to represent resources in the form of Subject Predicate Object triples; RDF Schema (RDFS) created together with its formal semantic within RDF is used to describe classes, properties and their relationships and we use them both to create a lightweight ontology. OWL is a language derived from description logic, and offers more constructs over RDFS. OWL is used to create a more expressive ontology [132,133].

Ontologies are used to derive data structures, schemas and interfaces which provide access to the data saved in the format of a given schema. During the development of such an ontology the following characteristics have to be taken into account according to [134]:

- The ontology has to be designed in a formal way so that it can be processed by machines.
- The ontology has to be reasonable for the task at hand. It should describe the problem domain reasonably well without containing too much information.
- The ontology represents the common understanding to all of its users have about a problem domain.

Accordingly, ontology representation of context can be applied in various scenarios of AAL applications. Ref [135] presents Ontology-based state representations of long-term activities of human for intention recognition in smart environments. Blodow et al. [136], Galindo [137] and Lorenz [138] proposed approach that uses ontology based semantic mapping for robots performing everyday manipulation tasks in kitchen environments. The projects in [139-141] use ontology to produce semantic modelling of space which can enhance human-robot interaction and navigation. Ambient home care systems (AHCS) in [130] are specially designed for healthcare which can collect heath status from ambient sensors and process the information with ontology. An ontology and rule based intelligent information system to detect and predict myocardial diseases is proposed by [142]. In [143], a formal representation of RAALI integration profiles is described by ontology based framework—AALOnto. Others instances of ontology-based context-awareness for AAL can be seen in [144-146].

5.3. Reasoning and planning

Reasoning and planning are intersective and conjunctive issues in the study of AAL system. The role of reasoning in context aware systems is to deduce and derive from the basic context information (includes information unknown, ambiguous, imprecise, and erroneous) to generate meaningful information and support system decision making. Planning concerns the problem of how to achieve a goal state starting from a known initial state. To achieve a goal, the system needs to deduce the existing knowledge based on the available context data. An entire process of planing produces a sequence or partially ordered collection of actions that if executed starting from the initial state, which is expected to achieve the goal state. There are several ways that planning can be used in AAL scenarios, for example in an AAL system, planning can be used to coordinate the capabilities of the available resources to provide a solution or perform a task; planning for AAL may have to deal with multiple agency; planners can be used, for example, to schedule task for specific status. Research in the area of AI planning has made notable progress over the last decade. There are many state-of-art reasoning and planning algorithms have impacted different application areas for AAL according to the surveys by [147-149].

The temporary-logic based approach concerns contextual information over time [150]. A temporal plan is a sequence of actions over the events that are maintained by temporal constraints. In such a plan logical preconditions describe under which circumstances an event may occur, its effects (or postconditions) describe the changes to the current world state after its occurrence [151,152]. In [153], the authors present a remarkable paradigm of AAL system planning with a temporal plan. They employ concepts drawn from constraint-based planning and execution frameworks in conjunction with efficient temporal reasoning techniques for human support. The planning framework uses a uniform formalism based on Allen's interval algebra to represent both the criteria for context recognition and a planning domain for AAL services. Ullberg [154] proposed a prototype of AAL system which utilises temporal constraints for continuous activity monitoring.

Case-based reasoning is capable of handling imperfect data and uncertain data as input for context aware. It is made and each new case that is evaluated referring to previously acquired cases. In general, case-based reasoning is suitable for carrying out online analysis, as efficient algorithms are already available for this task [155]. This method has been employed as a method for identifying situations in a dynamic environment. In [156], Case-based Reasoning and Case-based Planning are integrated as reasoning mechanisms into deliberative agents within a dynamic AAL environment. The AAL applications in [157,158] also demonstrate the use of Case-based reasoning.

Rule-based Reasoning is a typical reasoning approach which provides a formal model for context reasoning. It gives no inherent support for reasoning of incomplete data or the handling of uncertain information (probabilistic information). Besides, rule-based reasoning is easy to understand and has widespread use, and there are many systems that integrate them with the other model. Rule-based reasoning is well suited to online analysis and is also scalable to handle large amounts of data. However, it cannot handle highly changeable, ambiguous and imperfect context information. In AAL application, rules are mainly used to represent policies, constraints and preferences. [159]. Bikakis et al. [129] presented FOL rules to reason about context and to resolve possible conflicts, they have defined sets of rules on the classification and quality information of the context data. They suggest that different types of context have different levels of confidence and reliability. For example, defined context is more reliable compared to sensed and deduced context.

To reason and process the ontology based representation of contextual environment, semantic reasoning associated methods are required. Description-logic (DL)-based reasoning and Meta-logical (ML)-based reasoning are suitable for reasoning of OWL ontology [160-162]. Several semantic reasoning engines are developed to support the reason of ontology and among are the Jena framework, Pellet, and RacerPro [163-165] are primarily employed in the AAL community.

As many smart environment systems are agent-based, the reasoning and planning methods relevant to agent and multi-agent systems are considered to support AAL applications. BDI (Belief, Desire, Intention) is a essential reasoning model for multi-agent system. It is based on a philosophical model of human practical reasoning [166]. Beliefs are the information an agent has about its environment. Desires are goals assigned to the agent. Intentions are commitments by an agent to achieve particular goals. In other words, they are plans that are choices available to the agent at any moment of time to achieve its goals [167,168].

Plans are central to BDI model of agency. For instance, [156] presents a deliberative architecture model where the agents' internal structure and capabilities are based on mental aptitudes, using beliefs, desires and intentions. In the system, Case-Based Reasoning systems are integrated within deliberative BDI agents, facilitate learning and adaptation, and provide a greater degree of autonomy than pure BDI architecture. In [169], a Context-Aware Multi-Agent Planning (CAMAP) framework is proposed for intelligent environments. CAMAP is applied to a real-world application of AAL in the field of health-care with BDI method. Game theory has strong relation to multi-agent systems. In game theory agents act to maximise what is called their utility. The term utility is used in a very broad sense and refers to the amount of welfare an agent derives from an object or an event. Game theory can provide an explanatory account of strategic reasoning in AAL systems [8].

Besides, other approaches such as Fuzzy-logic Based Reasoning, Evidential Reasoning, Dempster–Shafer theory, Finite State Machine, Decision trees are commonly utilised in different levels of AAL application. Since AAL systems are heterogeneous and distributed, these approaches are integrated and hierarchised in different components and scenarios [17].

6. Conclusion and perspectives

In this work, we have explored many aspects of the research on AAL for older adults. The literatures and studies show the motivation and solutions of ALL for the well-being of older adults and deals with the problems of an aging society. The cognitive aspects of AAL are essential to achieve a better facilitation for users. AAL technology covers a broad range of research topics from ambient intelligence, assistive robotics, sensor networks, wearable sensors, internet of things, big data, etc. The emerging and tremendous progress of these technologies have made it possible to improve the older adults' daily life with AAL using wearable devices, health monitors, and smart walkers. However, there are still growing challenges that need to be addressed in the future.

Though the dramatic growth of IoT, wearable devices, cloud computing, advanced robotics, sensor networks, etc., have made various kinds of products available for assistive living. There is seldom of integration of these services to unleash the full power of AAL for healthcare, rehabilitation and assistive living. Integration of separate devices and services in larger systems benefits from collecting and processing large volumes of data, evaluating more complex situations and scenarios, collaborative tasking, precise identification of potentially dangerous situations and finding solutions. The integration of AAL services relates to interoperability, dynamic configuration, communication, context awareness (cognitive architectures), security and privacy. A mixture of these would probably be required to achieve the following outcome:

- The new generation of sensors should provide robust, high-precision perception of context and components related to assistive living. Besides, mobile and wearable devices need to be comfortable to wear and less obtrusive.
- Assistive devices and robots can be designed to enhance not only physical but also cognitive skills of human users through mobility experiences. They should be able to adapt to their gradual physical and cognitive decline, as well as to any sudden changes such as a hip fracture. Researchers and developers should pay attention to the combination of biological, physiological, medical aspects and robotics to develop intelligent cognitive robots for assistive service.
- Development of empirical models of social behaviour in a smart space, to enable context awareness of participants and environment.
- Proper framework for system coordination, components integration, service allocation, and knowledge sharing to support the operation of heterogeneous groups of AAL components.
- A set of global standards for a AAL service architecture enabling individual application development for a networked ecology of sensors, robots, mobile devices and data resources.

On the other side there are still gaps and obstacles between innovative AAL systems and different aspects of participants within the system. In the future, more user studies should be performed regarding the acceptance of AAL services and devices by the users, usability as well as the users' expectations of such assistive services. It is also essential to bring together all the stakeholders and enable the very important networking between policy makers, developers, producers, service providers, end user organisations, designers, health professionals (medical doctors, psychologists, rehabilitation nurse, etc.), sociologists, home carers, older adults and other potential end user groups.

In addition to the technological aspect of AAL, security and privacy problems have to be addressed. Within a complex networked system, a multitude of personal data will be collected. The future AAL systems should employ a variety of security methods based on biometric and physiological features to safeguard user privacy. Different levels of security should be granted to different users in such complex systems.

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